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Internal test morphology of the genus *Rectobolivina* (Cushman, 1927) from the Late Cenozoic Miyazaki Group, southwestern Japan

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Abstract. **Six species of the genus *Rectobolivina* (benthic foraminifera), *R. asanoi*, *R. bifrons*, *R. clavata*, *R. discontinuosa*, *R. raphana* and *R. striatula* from the Late Cenozoic Miyazaki Group of southwestern Japan were taxonomically studied, particularly focusing on internal test morphology. Two new species of *Rectobolivina*, *R. clavata* and *R. discontinuosa*, and one new replacement name, *Rectobolivina clavatostriatula*, are proposed. Scanning electron microscopic and optical microscopic observations of dissected specimens and thin sections reveal that the chamber wall of the genus *Rectobolivina* is bilamellar, and that the toothplate is an extension of the chamber wall, a twisted plate strongly folded at both edges and connecting successive foramina. The toothplate constantly attaches with one of its sides to the axial side of the inner margin of the preceding foramen. It exhibits a lamellar structure, showing that the extension of the outer lamella of the chamber wall is covered by two thin inner lamellae on both axial and peripheral sides.**

The six species of *Rectobolivina* display a clear stratigraphically separated distribution during the period from latest Miocene to earliest Pleistocene.

Key words: **benthic foraminifera, internal morphology, lamellar structure, Miyazaki Group, *Rectobolivina*, toothplate**

Introduction

The current classification scheme of benthic foraminifera requires examination of the internal test morphology (Loeblich and Tappan, 1987). This is mainly caused by the development of scanning electron microscopy (SEM) since the 1960's and of techniques for dissecting specimens.

The genus *Rectobolivina* proposed by Cushman (1927) differs from the genus *Siphogenerina* Schlumberger, 1882 by its biserial chamber arrangement in the earlier stage, in contrast to the triserial one in *Siphogenerina*. Hofker (1951a) indicated the importance of the toothplate of *Rectobolivina* at generic level, and Hofker (1951b) pointed out the difference of toothplate orientation between *Rectobolivina* and *Siphogenerina*. The current classification (Loeblich and Tappan, 1964, 1987) adopted the significance of the toothplate orientation. Although Revets (1993) briefly described the monolamellar structure in the toothplate of the genus *Siphogenerinoides* Cushman, 1927, which shows the same toothplate orientation as *Rectobolivina*, the structure of the toothplate in *Rectobolivina* has not yet been described.

The present paper deals with the taxonomy of *Rectobolivina* species from the Late Cenozoic Miyazaki Group, with emphasis on the nature of the toothplate.

Geologic settings

On the coastal region of Miyazaki Prefecture, southeast Kyushu, Late Cenozoic marine deposits named the Miyazaki Group are widely distributed. The Miyazaki Group unconformably overlies the Paleogene unit of the Shimanto Supergroup. Shuto (1952) divided the Miyazaki Group into three facies, the Aoshima, the Miyazaki, and the Tsuma facies from south to north, based on lithological differences and on their geographic distribution. The relationship among these facies has been thought to be contemporaneous. Shuto (1952) divided the Tsuma facies into three members, the Kawabaru, the Tsuma, and the

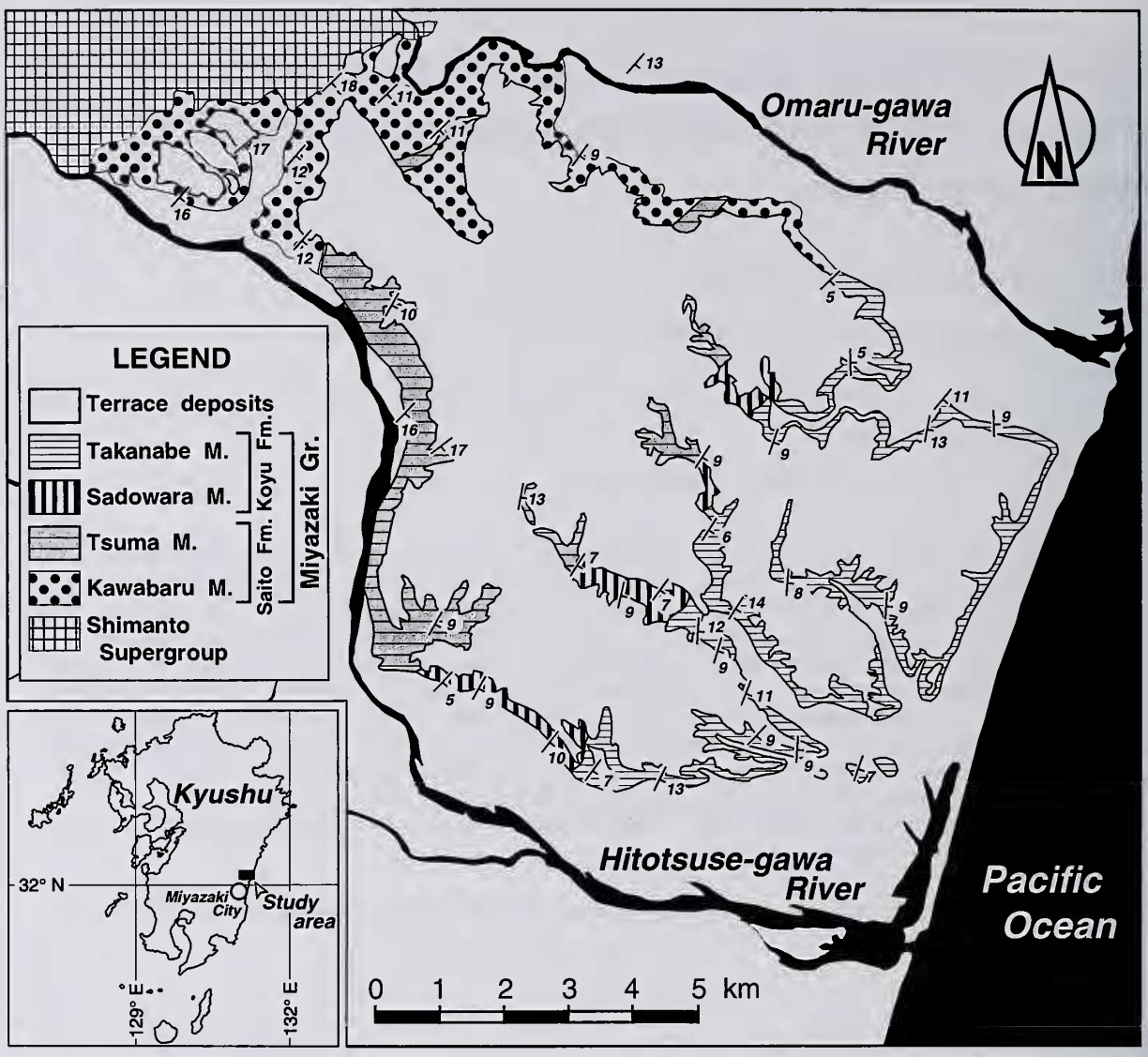


Figure 1. Geologic map of the study area (modified after Suzuki, 1987).

Takanabe Member in ascending order. The Tsuma facies was reclassified and subdivided into four members by Suzuki (1987) as follows: the Kawabaru and Tsuma Members of the Saito Formation, and the Sadowara and Takanabe Members of the Koyu Formation in stratigraphic order (Figure 1). The geologic age of the group was previously assigned to latest Miocene to earliest Pleistocene based on planktonic foraminifera by Natori *et al.* (1972) and calcareous nannoplankton by Nishida (1980).

The Tsuma facies is well exposed at the terrace cliffs along the Hitotsuse-gawa River. We collected 59 sediment samples for this study from this section (Figure 2).

Materials and methods

Lithology and horizons of foraminifera-bearing rock samples in the section along the Hitotsuse-gawa River are shown in Figure 3. The pelitic layers in a siltstone/sandstone alternation were selected for sampling. Rock samples were disintegrated with an oversaturated sodium sulfate (Na_2SO_4) solution following the method of Ujiié *et al.* (1977) and were washed using a 74 μm sieve.

Rectobolivina specimens were picked out from the sediment residue on the sieve and identified with optical and scanning electron microscopes (SEM). A number of megalospheric specimens were dissected and observed under SEM following Nomura's (1983) Canada balsam-

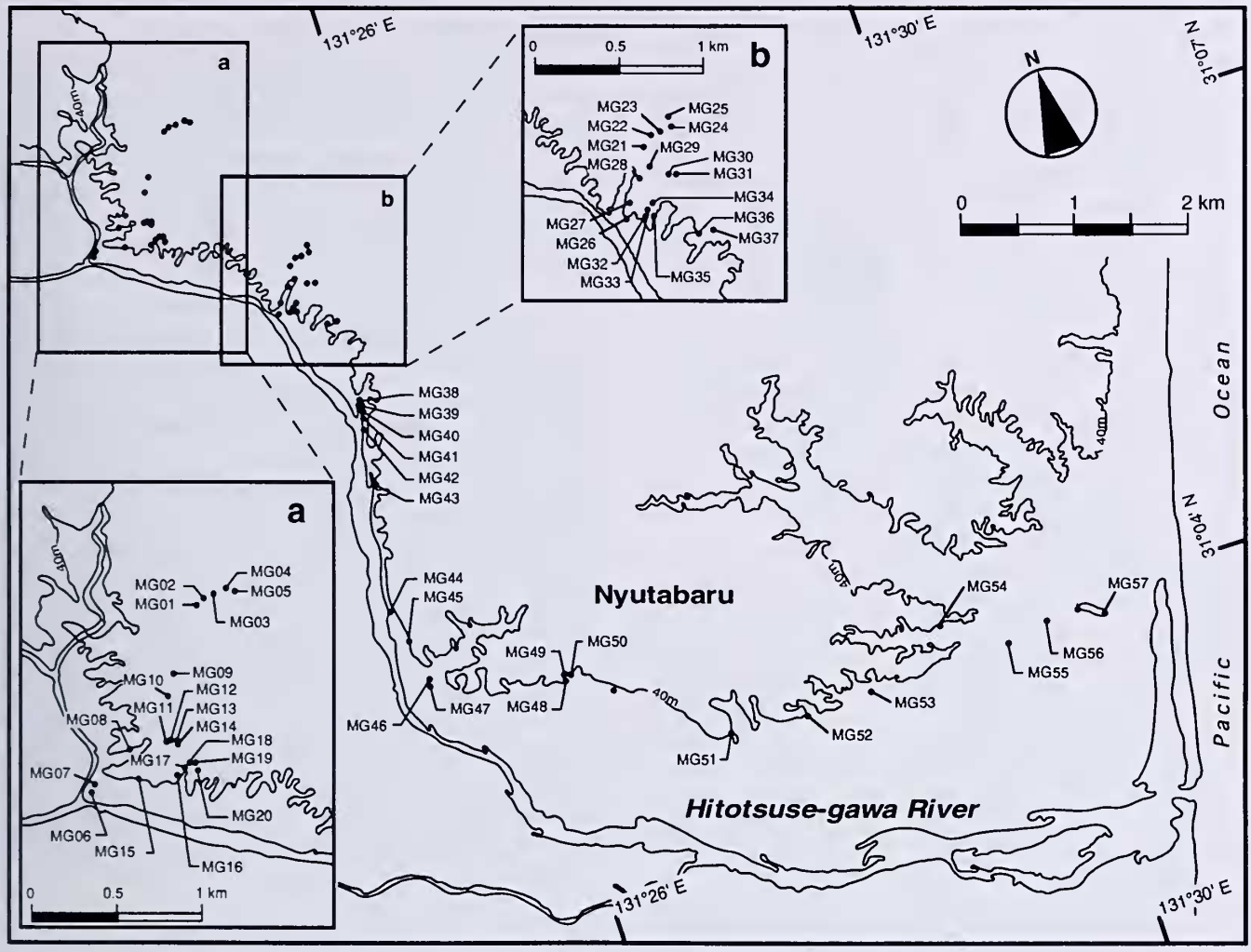


Figure 2. Map showing sampling localities.

xylene embedding method to examine the internal test structures.

All the illustrated specimens are deposited in the collections of the University of Tsukuba with catalog number prefixed IGUT.

Brief note on stratigraphic occurrence

Rectobolivina asanoi Murata, 1951, *R. bifrons* (Brady, 1881), *R. clavata* sp. nov., *R. discontinuosa* sp. nov., *R. raphana* (Parker and Jones, 1865), and *R. striatula* (Cushman, 1913) were recognized in 35 sampling horizons (Figure 4). As shown in Figure 5, the stratigraphic distribution and the frequency of occurrence of these species are different in the study section. *R. asanoi* characteristically occurs only in the Kawabaru Member of uppermost Miocene age. *R. bifrons* and *R. striatula* occur at two horizons in the upper part of the Kawabaru Member and in the lower part of the Tsuma Member, while *R. clavata* sp. nov. is characteristic at two horizons, one in the upper part of the Tsuma Member and another in the lower part of the Sadowara Member. *R. raphana* occurs in the Takanabe Member. *R. discontinuosa* sp. nov. is restricted to the lowest Pleistocene horizon of the Takanabe Member. Possibly, these stratigraphic distributions of the species may offer clues for the restricted but detailed correlation of strata in a further study.

Previous studies on toothplate of *Rectobolivina*

Although Brady (1881, 1884) did not mention the existence of the toothplate in the original description of *Sagrina bifrons* (type species of *Rectobolivina*), Cushman (1913) described "the internal tubular connection" of *R. bifrons*

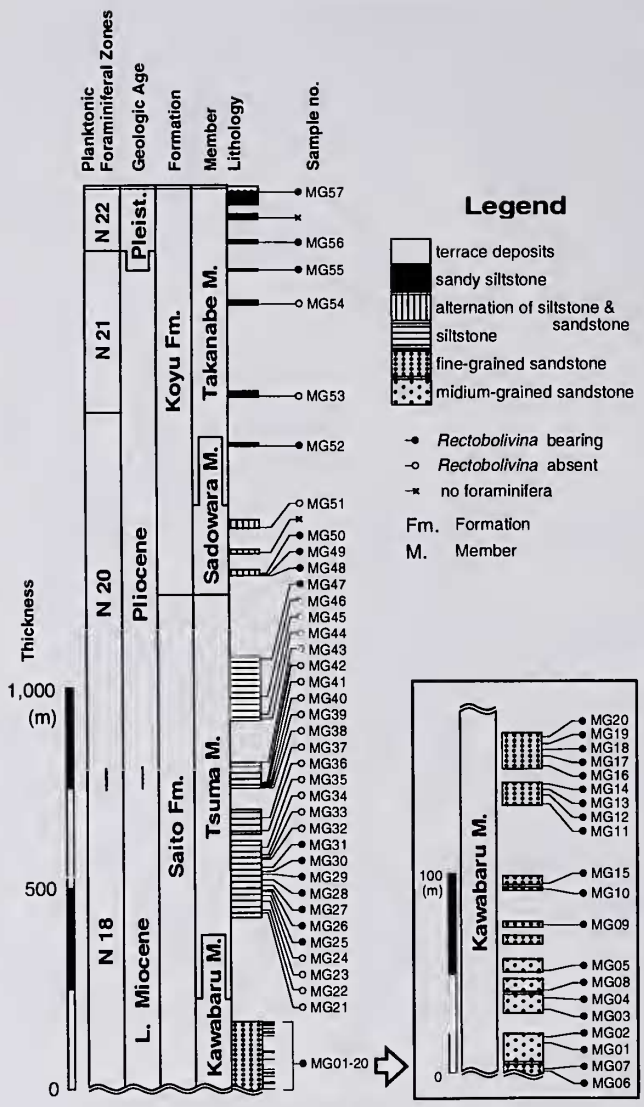


Figure 3. Geologic columnar section with the sampling levels. Stratigraphic division and thickness calculation are based on Suzuki (1987), and geologic age and planktonic foraminiferal zones are after Natori *et al.* (1972).

(his *Siphogenerina bifrons*) based on observations by optical microscopy. Cushman (1927, 1937) described the toothplate as "tube" or "tubular", and Hofker (1933) called it an "internal tube". Later, Hofker (1951a) examined toothplates of foraminifera including *Rectobolivina* species, and stated, "...in the biserial part of *Rectobolivina*, this plate is fastened at one side of the aperture of the former chamber, and is erected in such way, that, by contorting itself, it is attached to the opposite side of the chamber itself, giving rise to a tooth by means of its folded and flaring side...". He (fig. 35) illustrated in detail the schematic succession of toothplates in relation to the chamber arrangement for some *Rectobolivina* species, particularly for *Rectobolivina columellaris* (Brady). He first showed that the toothplate of the genus is not a cylindrical tube but is a hemicylindrical plate. Hofker (1951b) showed the different modes of toothplate orientation in *Rectobolivina* and its related genus *Siphogenerina*; the angle between successive toothplates in *Rectobolivina* is constantly 180°, whereas it is 120° in *Siphogenerina*. Thus, the morphology and succession of the toothplates are now regarded as important taxonomic features. Loeblich and Tappan (1964) adopted Hofker's (1951b) opinion in their classification scheme of foraminifera and placed *Rectobolivina* into the family Bolivinitidae Cushman, 1927. They used the term "toothplate" only for the superfamily Buliminoidea (= their Buliminacea). Later, Loeblich and Tappan (1987) moved *Rectobolivina* into the subfamily Siphogenerinoidinae Saidova, 1981. The Siphogenerinoidinae consists of 11 genera, including *Rectobolivina* but not *Siphogenerina*, which are characterized by biserial chamber arrangement in earlier stage becoming uniserial in later stage, associated with the toothplate rotating 180° between chambers. Loeblich and Tappan (1987) defined the toothplate as an extension of the chamber wall and a contorted plate extending within the chamber lumen. Recently, Revets (1989, 1993, 1996) pointed out that the toothplate of the Buliminoidea (= his Buliminacea) (including *Rectobolivina*) originated from the inner layer of a bilamellar chamber wall, and he distinguished it from the so-called "toothplate" in the Rotalioidea, which shows a more complicated structure.

Toothplate in *Rectobolivina*

Megalospheric specimens were vertically sectioned in two ways (Figure 6); i.e. cut through the broader diameter of test (Section A) and perpendicularly (section B).

The following description can be applied to all species treated here. The relationship among toothplate, foramen and chamber lumen is schematically shown in Figure 7.

The aperture of *Rectobolivina* species is elliptical to circular in outline and its top fuses to the apertural lip, which never distinctly protrudes (Figure 4). The toothplate is apparently thin and trough-shaped, strongly folded at its side edges as seen in section A (e.g. Figures 8.2, 11.7). The plate in the uniserial stage descends straight into the chamber lumen towards the preceding foramen, along the center of the test (e.g. Figure 10.5), whereas it extends in a zigzag way in the biserial stage, according to the biserial chamber arrangement (e.g. Figure 10.5). The trough-shaped concavity (tc) of the toothplate appears alternately from chamber to chamber in both biserial and uniserial stages (e.g. Figure 8.2). This indicates that the toothplate retains the early ontogenic biserial (= 180°) rotation, although cham-

bers become uniserial.

After slight etching with dilute hydrochloric acid solution, the chamber wall of *R. bifrons* (type species of the genus) shows a lamellar structure (Figure 8.5). The later chamber wall entirely covers the preceding ones, causing the thickening of the test wall in the earlier portion. The final chamber wall of *R. raphana* (Figure 11.4) is bilamellar, consisting of a thin inner lamella (il) and a thick outer lamella (ol). A similar lamellar structure can be seen in the toothplate (tp) of *R. bifrons* (Figure 9.2, 9.3), where a thick outer lamella (ol) is covered by a thin inner lamella (il) at both the axial and peripheral sides. In conclusion, it can be stated that the lamellae of the toothplate do not originate in the preceding toothplate nor septal wall, but represent an extension of the chamber wall (Figures 8.1, 9.2, 9.3, 9.5, 9.6). These observations on the lamellar structure of the toothplate differ from those by Revets (1989, 1993), who regarded the toothplate as an extension of the inner lining (= inner lamella in this study) of the chamber wall.

Our observation of the internal, lamellar structure in the genus *Rectobolivina* is summarized in Figure 12, and supports Hofker's (1951a) idea that the toothplate is a part of the chamber wall.

Systematic description

Family Siphogenerinoidae Saidova, 1981
Subfamily Siphogenerinoidinae Saidova, 1981
Genus ***Rectobolivina*** Cushman, 1927

Rectobolivina asanoi Murata, 1951

Figures 4.1a–c, 4.2a–c; 10.1, 10.2; 13.1a, b

Rectobolivina asanoi Murata, 1951, p. 96, pl. 1, text-figs. 2a, b; Asano, 1952, p. 13, figs. 70, 71; Kawagata, 2001, p. 88, figs. 8–13a, b.

Rectobolivina bifrons striatula (Cushman) (non *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917). Asano, 1950, p. 12, figs. 48, 49; Matsunaga, 1963, pl. 41, figs. 9a, b.

Material.—IGUT14488, sample MK07(Figure 4.1a–c); IGUT14489, sample MK07(Figure 4.2a–c); IGUT14490, sample MK07 (Figure 10.1); IGUT14491, sample MK07 (Figure 10.2).

Remarks.—Since Murata (1951) described *Rectobolivina asanoi* from the Miocene part of the Miyazaki Group, this species has been reported only from the late Neogene Shimajiri Group in Kume-jima Island, southwestern Japan (Kawagata, 2001). Comparing the original figure of *R. asanoi* Murata, 1951 (Figure 11.1a) to other costate *Rectobolivina* species, the former species is characterized in having a much wider test, and being elliptically rounded in cross section. *R. bifrons* var. *striatula* (Cushman, 1917) of Suzuki (1987) from the lower part of the Miyazaki Group, south of the present study area, of Asano (1950) from the Pliocene Kakegawa Group, central Japan, and of Matsunaga (1963) from the Pliocene in Niigata Prefecture, northeastern Japan, are all probably identical to *R. asanoi*. The specimens treated here resemble those described as *R. striatula* (Cushman, 1917) from the late Neogene of New Zealand (Hornibrook, 1968; Hayward and Buzas, 1979) and from the Miocene of Victoria, Australia (Carter, 1964), and those described as *R. striatula* (Cushman, 1913) of Kennett (1966) from the late Neogene of New Zealand. However, these Southern Ocean species show cylindrical tests with numerous fine longitudinal striations (Carter, 1964; Kennett, 1966) or with fewer costae (Hornibrook, 1968; Hayward and Buzas, 1979), in contrast to the rather compressed test with a number of raised longitudinal costae in *R. asanoi*.

The megalospheric form of *R. asanoi* shows a bluntly rounded initial end and approximately four to five pairs of chambers in the biserial stage (Figure 4.1a, c), whereas the microspheric form has a rather tapered initial end and more chamber pairs in the earlier stage (Figure 4.2a, c). There is no distinct size difference between the forms.

Rectobolivina bifrons (Brady, 1881)

Figures 4.3a–c, 4.4a–c; 8.2–8.5; 9.1–9.6; 13.2–13.4b

Sagrina bifrons Brady, 1881, p. 64; Brady, 1884, p. 582, pl. 75, figs. 18–20.

Siphogenerina bifrons (Brady). Cushman, 1913, p. 103, pl. 45, figs. 1a–2, 5–7; Cushman, 1921, p. 277, pl. 56, figs. 2, 3; Cushman, 1926, p. 16, pl. 3, figs. 7–9, pl. 4, fig. 4.

Rectobolivina bifrons (Brady). Cushman, 1927, p. 68, pl. 14, fig. 11; Cushman, 1937, p. 204, pl. 23, figs. 13, 14a, b; Asano, 1938, p. 606, pl. 16, figs. 11a, b; Asano, 1950, p. 11, figs. 46, 47; Asano, 1958, p. 28, pl. 5, figs. 10, 11; Kuwano, 1962, pl. 21, fig. 6; Huang, 1964, pl. 2, fig. 28; Ishiwada, 1964, pl. 4, fig. 68; Kikuchi, 1964, pl. 3, fig. 23; Belford, 1966, p. 45, pl. 9, figs. 13, 14; Inoue, 1989, pl. 28, fig. 6.

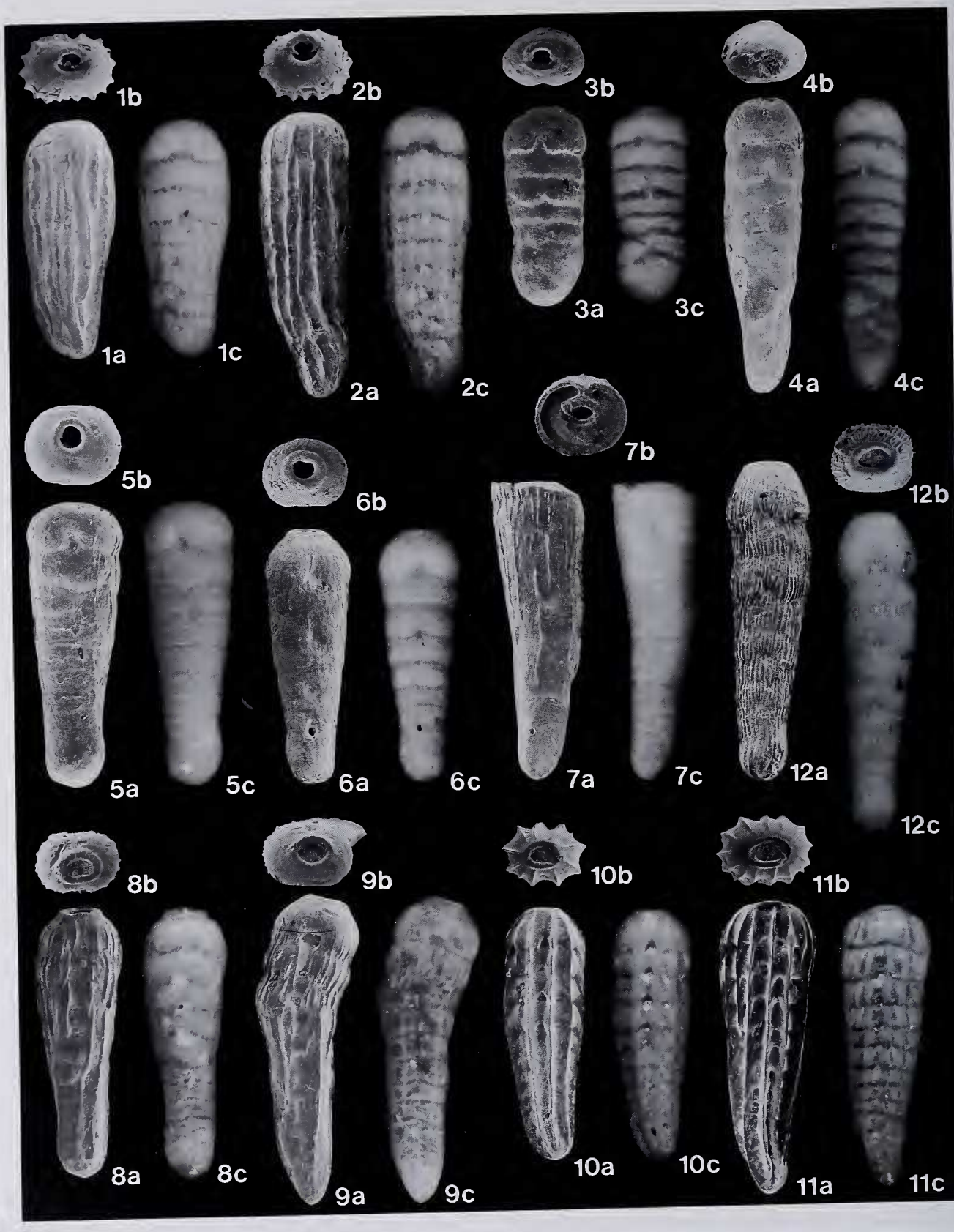
? *Siphogenerina* (*Sagrina*) *bifrons* (Brady). Egger, 1893, p. 317, pl. 4, figs. 25, 26, 29.

? *Rectobolivina bifrons* (Brady). Matsunaga, 1963, pl. 41, figs. 8a, b; Saidova, 1975, pl. 86, figs. 9, 10.

not *Rectobolivina bifrons* (Brady). LeRoy, 1964, p. F34, pl. 3, figs. 1, 2; Loeblich and Tappan, 1964, p. C553, fig. 438, nos. 2a–5b.

not *Rectobolivina* cf. *bifrons* (Brady). McCulloch, 1977, p. 259, pl. 107, figs. 17a, b.

Material.—IGUT14492, sample MK19 (Figure 4.3a–c); IGUT14493, sample MK19 (Figure 4.4a–c); IGUT14494, sample MK19 (Figure 8.2); IGUT14495, sample MK19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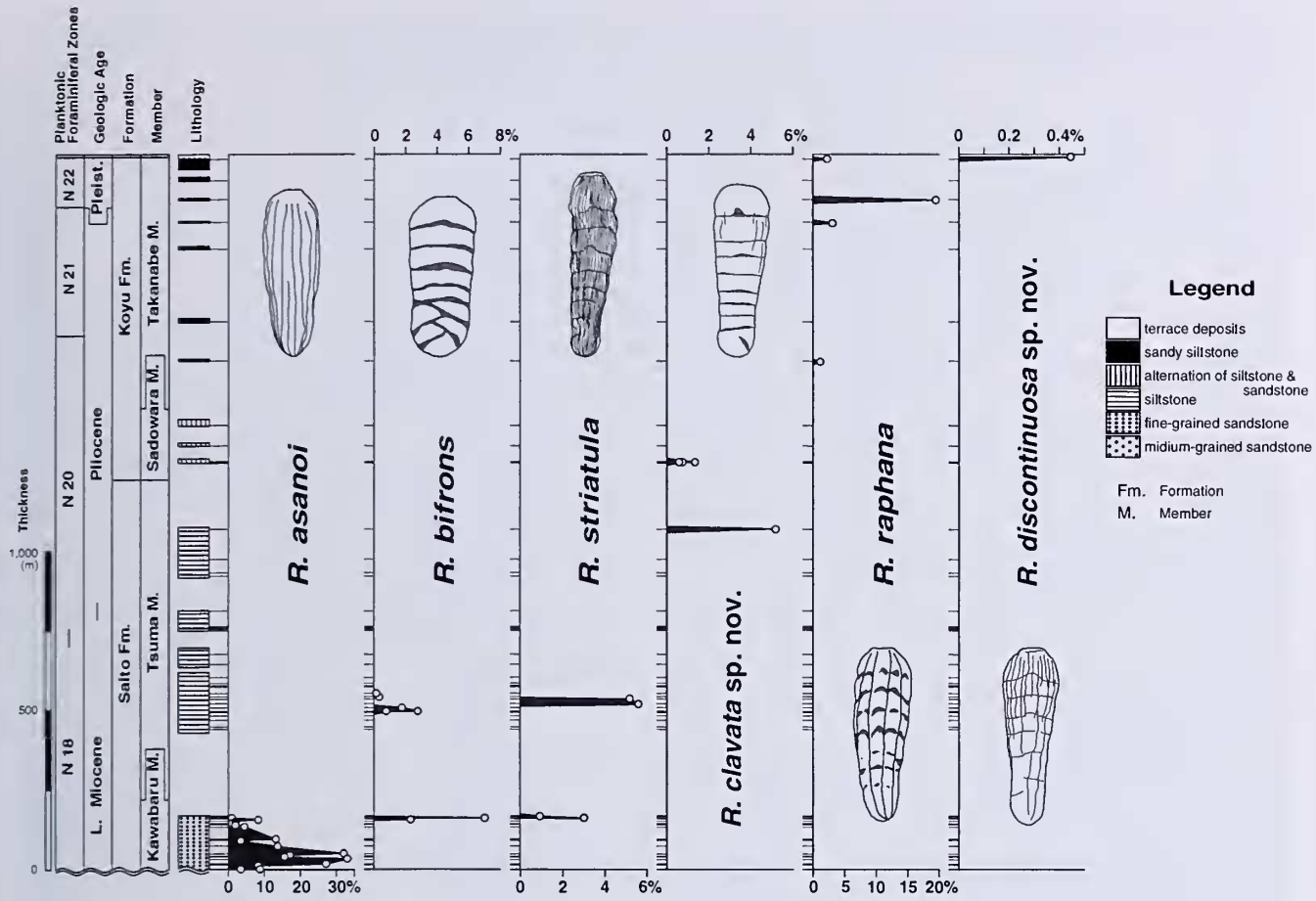


Figure 5. Stratigraphic occurrence and percentage abundance of six *Rectobolivina* species in the study section of the Miyazaki Group.

← **Figure 4.** **1a–c.** Megalospheric form of *Rectobolivina asanoi* (Murata), IGUT14488, 1a: side, 1b: apertural views, ×60. 1c: Optical microphotograph of 1a, ×60. **2a–c.** Microspheric form of *Rectobolivina asanoi* (Murata), IGUT14489, 2a: side, 2b: apertural views, ×60. 2c: Optical microphotograph of 2a, ×60. **3a–c.** Megalospheric form of *Rectobolivina bifrons* (Brady), IGUT14492, 3a: side, 3b: apertural views, ×60. 3c: Optical microphotograph of 3a, ×60. **4a–c.** Microspheric form of *Rectobolivina bifrons* (Brady), IGUT14493, 4a: side, 4b: apertural views, ×60. 4c: Optical microphotograph of 4a, ×60. **5a–c** (holotype), IGUT14499, and **6a–c** (paratype), IGUT14500. Megalosphcric form of *Rectobolivina clavata* sp. nov., 5a: side, 5b: apertural views, ×60. 5c: Optical microphotograph of 5a, ×60; 6a: side, 6b: apertural views, ×50. 6c: Optical microphotograph of 6a, ×50. **7a–c.** Microspheric form of *Rectobolivina clavata* 2p. nov, IGUT14501, 7a: side, 7b: apertural views, ×50. 7c: Optical microphotograph of 7a, ×50. **8a–c.** Megalospheric form of *Rectobolivina discontinuosa* sp. nov. (holotype), IGUT14504, 8a: side, 8b: apertural views, ×50. 8c: Optical microphotograph of 8a, ×50. **9a–c.** Microspheric form of *Rectobolivina discontinuosa* sp. nov. (paratype), IGUT14505, 9a: side, 9b: apertural views, ×50. 9c: Optical microphotograph of 9a, ×50. **10a–c** and **11a–c.** Megalospheric form of *Rectobolivina raphana* (Parker and Jones), IGUT14508 and IGUT14509, 10a: side, 10b: apertural views, ×50. 10c: Optical microphotograph of 10a, ×50; 11a, IGUT14509: side, 11b: apertural views, ×50. 11c: Optical microphotograph of 11a, ×50. **12a–c.** Megalospheric form of *Rectobolivina striatula* (Cushman), IGUT14513, 12a: side, 12b: apertural views, ×50. 12c: Optical microphotograph of 12a, ×50.

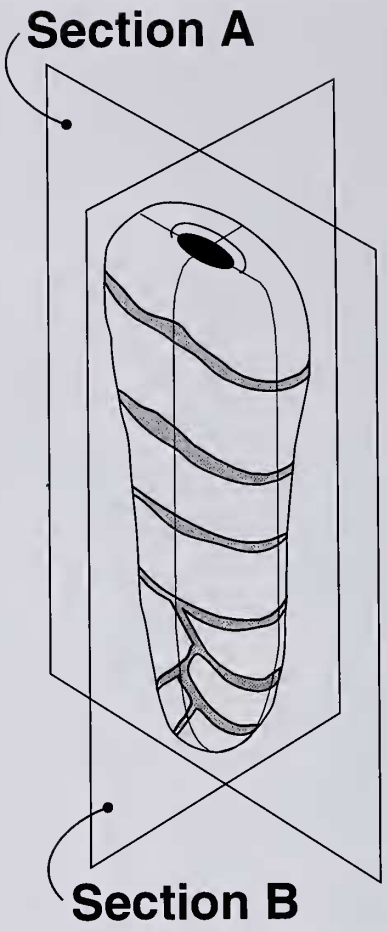


Figure 6. Diagram showing the two sections of a foraminiferal test used in this study.

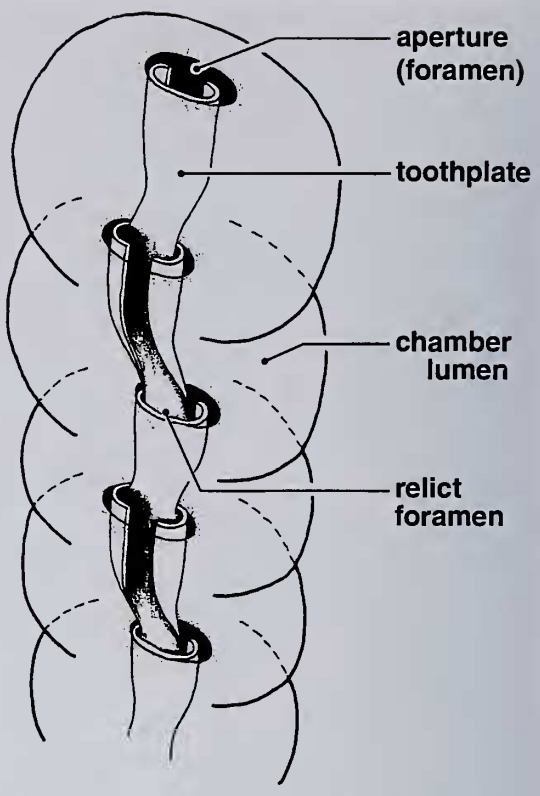


Figure 7. A schematic sketch of the *Rectobolivina* species showing the relationship among toothplate, foramina and chamber lumina in the uniserial stage. Terms follow Revets (1989, 1993).

(Figure 8.3); IGUT14496, sample MK19 (Figure 8.4); IGUT14497, sample MK19 (Figures 8.5, 9.1–9.2); IGUT 14498, sample MK19 (Figures 9.4–9.5).

Remarks.—This species was first described by Brady (1881) from off the Pacific coast of central Japan, and the original figures by Brady (1884) are reproduced in Figure 13.2–13.4b. Cushman (1913) examined both megalospheric and microspheric forms of the species and pointed out that all Brady's original figures represent megalospheric forms. Many specimens treated here are megalospheric forms (e.g. Figure 4.3a–c), which compare well with Brady's original figures. The megalospheric form is much shorter than the microspheric one, because of the reduced chamber number at the biserial stage.

Rectobolivina clavata sp. nov.

Figures 4.5a–c, 4.6a–c, 4.7a–c; 10.3, 10.4

? *Rectobolivina bifrons* (Brady). LeRoy, 1964 (non *Sagrina bifrons* Brady, 1881), p. F34, pl. 3, figs. 1, 2.

Diagnosis.—A species of *Rectobolivina* with a clavate-shaped and inornate test.

Description.—Test free, moderate size, approximately four times as long as broad, straight, clavate in shape, elliptical in being laterally depressed in cross section, initial end bluntly rounded in megalospheric form, whereas initial end pointed in microspheric form; chambers numerous, breadth twice the height, gradually increasing in size added changing from uniserial to biserial, after the third chamber in megalospheric form or after the tenth chamber in microspheric form; wall calcareous, optically radial, transparent or semitransparent, finely perforate, rather thick, sometimes very weakly striate in later part of test; sutures distinct, moderately thick, slightly depressed; aperture terminal, nearly circular to elliptical opening, with a distinct but slightly protruding lip; intercameral septa thick as well as the wall, parallel to slightly arched; toothplate folded at the lateral edge, extending into the preceding aperture (foramen), its folded face arranged alternately in planes 180° apart.

Material.—Holotype: IGUT14499 (1.03 mm in length,

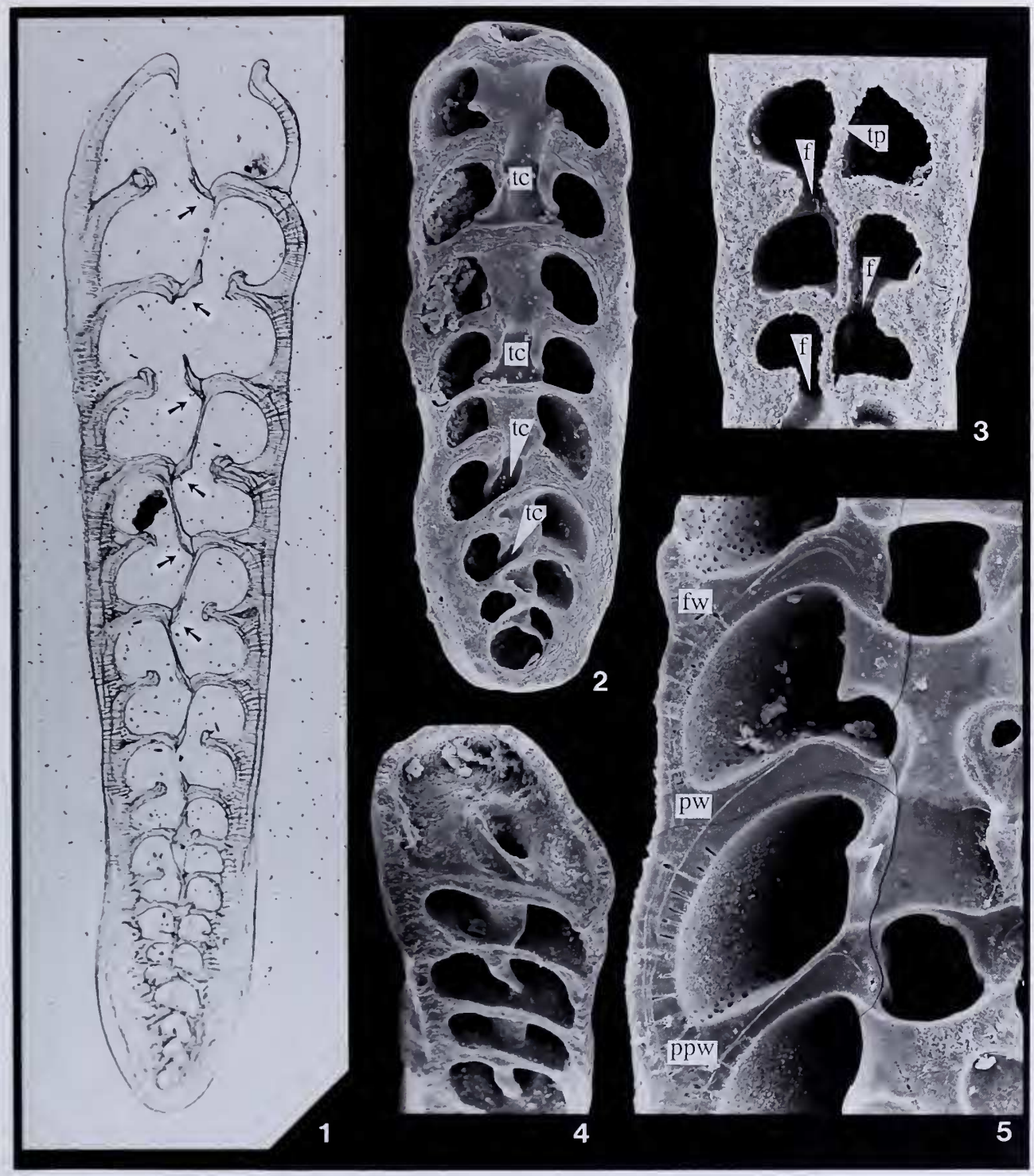


Figure 8. Sections of the microspheric form of *Rectobolivina raphana* (Parker and Jones) (8.1) and the megalospheric forms of *Rectobolivina bifrons* (Brady) (8.2–8.5), IGUT14494- IGUT14497. **1**. Overall view of Section B (Figure 6). Arrows indicate the attached portion of the toothplates, which never continuously extend from the preceding toothplate or septa, ×143. **2**. Overall view of Section A. Concave side of trough-shaped plate (tc) which rotates 180° between chambers, ×180. **3**. A part of the uniserial stage in Section B. Foramen (f) opens alternately along toothplate (tp). Toothplate always runs along the centre of chamber lumen, ×350. **4**. Oblique section showing relationship between foramen and toothplate, ×250. **5**. A part of test wall showing lamellar development of test wall according to test growth. Final chamber wall (fw) covers wall of penultimate chamber (pw), and pw covers over the pre-penultimate chamber wall (ppw), ×500.

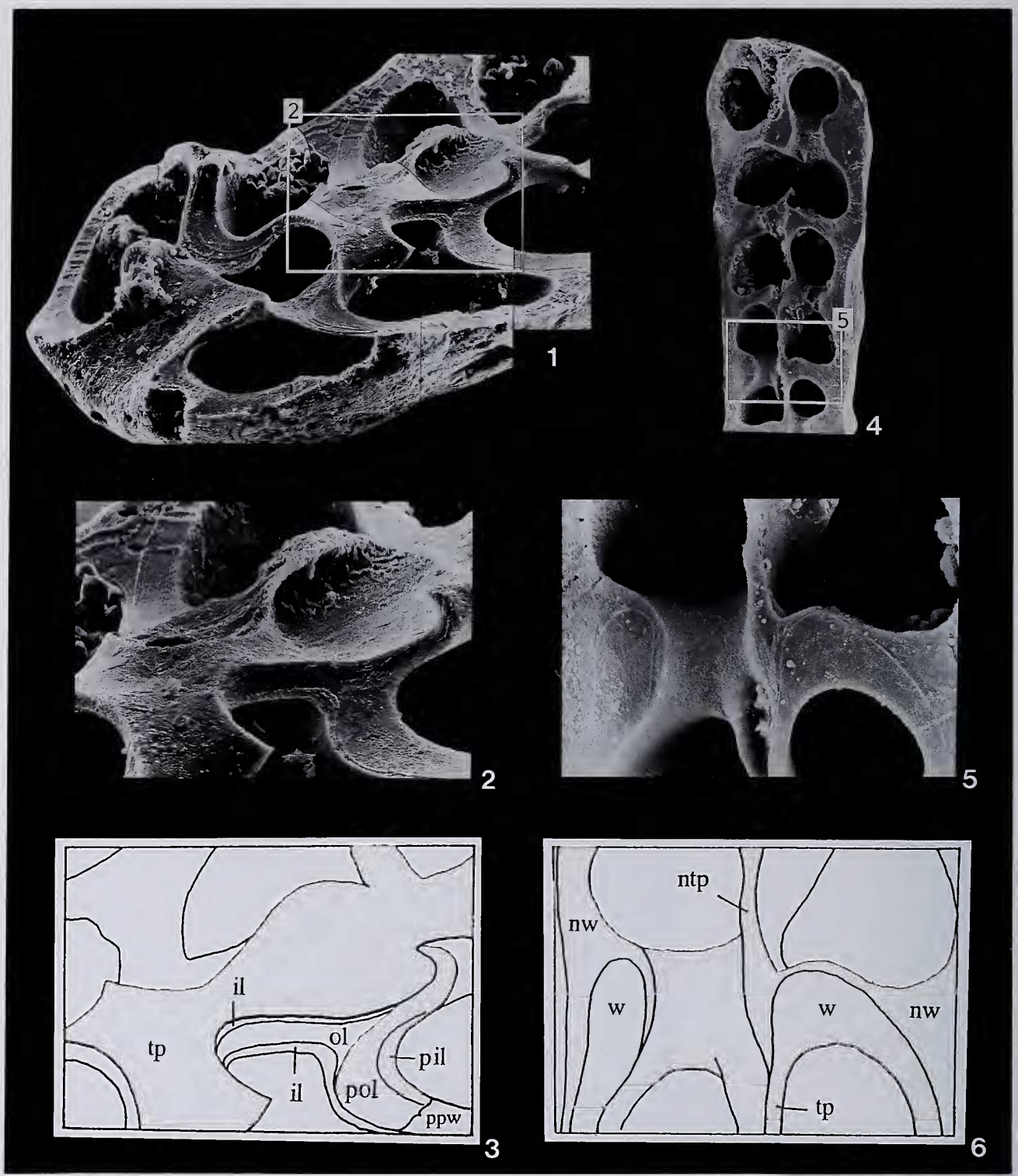


Figure 9. Megalospheric forms of *Rectobolivina bifrons* (Brady). 9.1, 9.2, IGUT14497. **1**. Oblique view of later part of test of the same specimen shown in Figure 8.5, ×450. **2, 3**. Close-up photograph and its sketch, showing lamellar structure of toothplate (tp) in the penultimate chamber. A thick outer lamella (ol) is intercalated with two inner lamellae (il), and attaches to pre-penultimate chamber wall (ppw) composed of previous outer (pol) and inner layers (pil), ×800. **4, 5**. IGUT14498, 4. A part of the uniserial stage in Section B (Figure 6), ×180. **5, 6**. Close-up photograph and its sketch, are showing the attachment portion of toothplate (tp). Toothplate (tp), a part of chamber wall (w), is separated from next toothplate (ntp) which is a part of next chamber wall (nw), ×700.

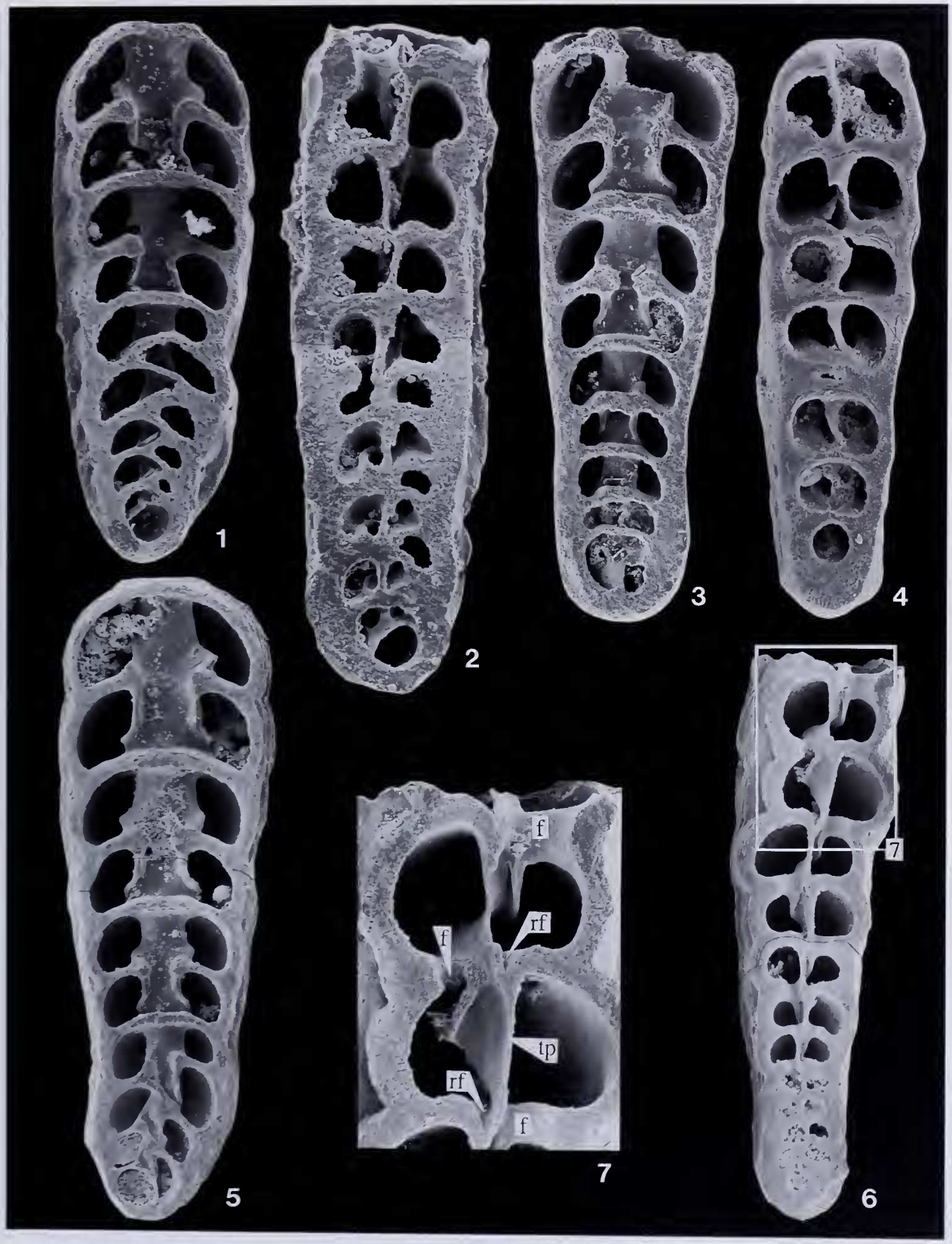
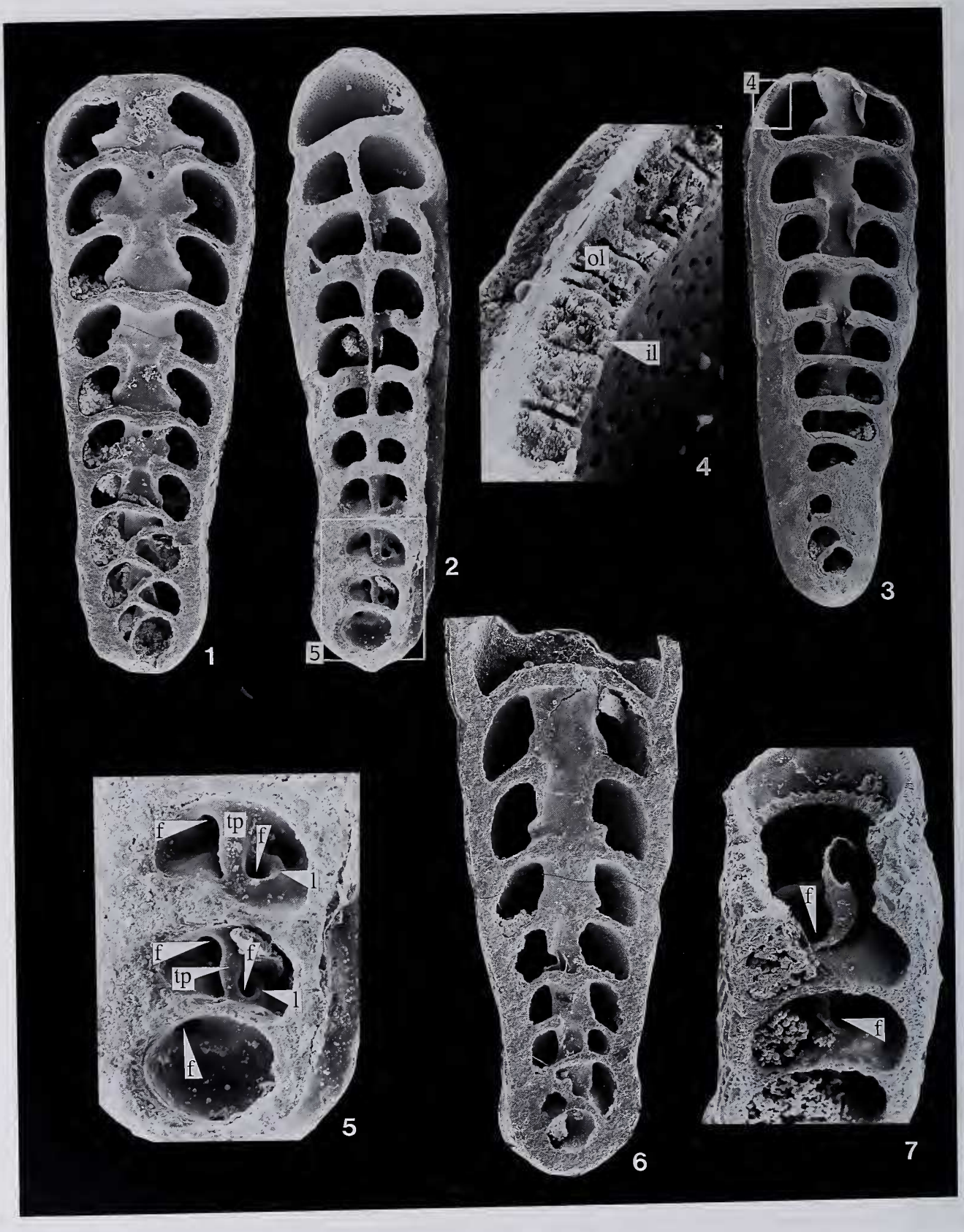


Figure 10. All dissected specimens are the megalospheric forms. **1, 2**. Sections A and B (see Figure 6) of *Rectobolivina asanoi* (Murata), respectively, IGUT14490 and IGUT14491, ×150 and 200. **3, 4**. Sections A and B of *Rectobolivina clavata* sp. nov., respectively, IGUT14502 and IGUT14503, ×150 and 200. **5, 6**. Sections A and B of *Rectobolivina discontinuosa* sp. nov., respectively, IGUT14506 and IGUT14507, ×120. **7**. Close-up of a part of 6, showing the relationship among toothplate (tp), foramen (f) and relict foramen (rf), ×250.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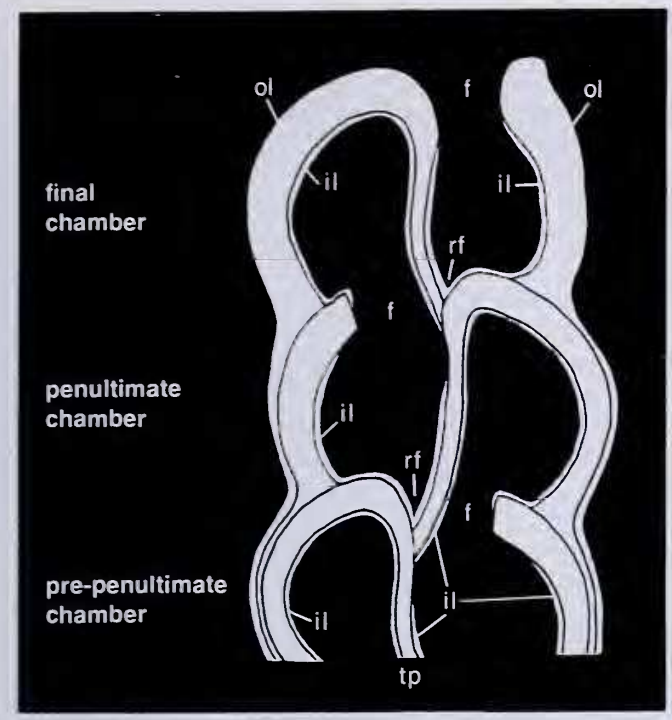


Figure 12. A schematic figure of the lamellar structure of the test wall and the toothplate in Section B (see Figure 6), showing foramen (f), toothplate (tp), outer lamella (ol), inner lamella (il), and relict foramen (rf). The terms used in the figure mostly follow Revets (1989, 1993).

0.36 mm in maximum breadth), sample MK48 (Figure 4.5a–c). Paratypes: IGUT14500 (0.92 mm in length, 0.32 mm in maximum breadth), sample MK48 (Figure 4.6a–c); IGUT14501 (1.08 mm in length, 0.34 mm in maximum breadth), sample MK48 (Figure 4.7a–c); IGUT14502, sample MK48 (Figure 10.3); IGUT14503, sample MK48 (Figure 10.4).

Etymology.—The specific name, *clavata*, is derived from the clavate-shape of the test.

Remarks.—This new species has a more slender and more clavate-shaped test than *R. bifrons* (Brady). According to measurements of the test width (TW) in megalospheric forms of *R. bifrons* and *R. clavata* (Figure 14), the test width of *R. clavata* becomes narrowest at the fourth chamber, whereas that of *R. bifrons* constantly increases (Figure 15). Furthermore, the former has a single pair of biserial chambers, whereas the latter has several pairs of biserial chambers. *R. clavata* differs from *Rectobolivina columellaris* (Brady, 1881) in having a more compressed test, in contrast to the cylindrical test of the latter species. An Australian *Rectobolivina* species, described as *Sagrina sydneyensis* by Goddard and Jensen (1907), differs from *R. clavata* in having ornamentation with minute spines and some large pores.

Rectobolivina striatula (Cushman, 1913)

Figures 4.12a–c; 11.6, 11.7; 13.11a, b

Siphogenerina striatula Cushman, 1913, p. 108, pl. 47, fig. 1.

Rectobolivina bifrons (Brady) var. *striatula* (Cushman, 1917). LeRoy, 1964 (non *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917, nomen nudum), p. F34, pl. 3, figs. 5, 6.

? *Rectobolivina bifrons* (Brady) var. *striatula* (Cushman, 1917). LeRoy, 1941a (non *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917, nomen nudum), p. 35, pl. 2, figs. 7, 8.

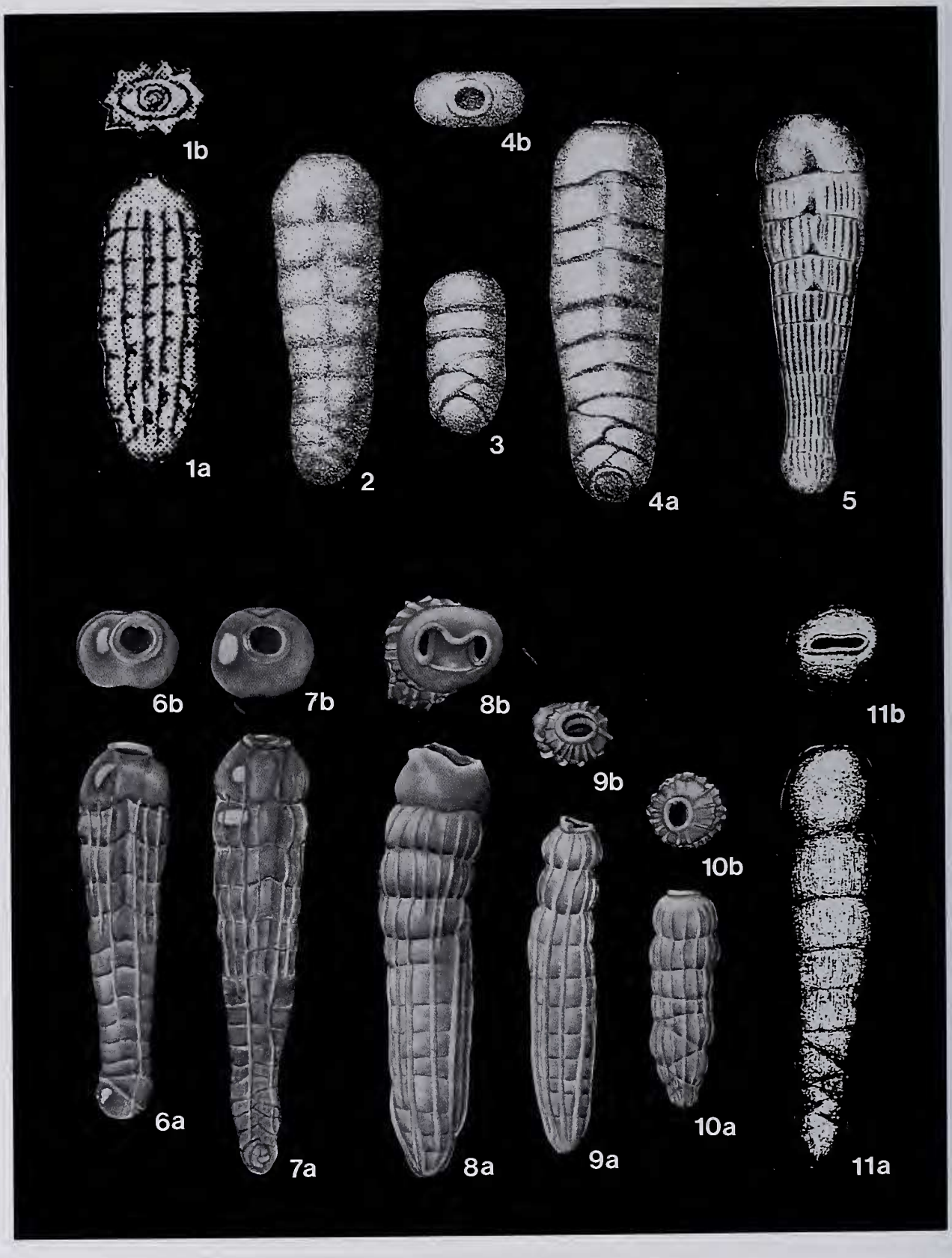
not *Rectobolivina striatula* (Cushman, 1917) (non *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917, nomen nudum). Carter, 1964, p. 69, pl. 2, figs. 35, 36; Hornibrook, 1968, p.73, fig. 13 (part), Hayward and Buzas, 1979, p. 72, pl. 26, figs. 320, 321.

not *Rectobolivina striatula* (Cushman, 1913). Kennett, 1966 (non *Siphogenerina striatula* Cushman, 1913), p. 47, fig. 59.

Material.—IGUT14513, sample MK19 (Figure 4.12a–c); IGUT14514, sample MK19 (Figure 11.6); IGUT14515, sample MK19(Figure 11.7).

Remarks.—All specimens of the present species from the Miyazaki Group are regarded as megalospheric forms because they are characterized in having a bluntly rounded initial end (Figure 4.12a, c) and three pairs of biserial chambers at the earliest part (Figure 11.6). This species is distinguished from the other *Rectobolivina* species in having numerous, fine, and longitudinal striations covering the test surface (Figure 4.12a). Compared with Cushman's (1913) original figure of the type specimen (here reproduced in Figure 13.11a, b), our specimens have a slightly rhomboidal outline in section and an elliptically rounded aperture, in contrast to the rounded outline and rather narrow slit-like aperture in the type specimen.

← **Figure 11.** All dissected specimens are megalospheric forms. **1, 2.** Sections A and B (see Figure 6) of *Rectobolivina raphana*, respectively, IGUT14510 and IGUT14511, ×120 and 150. **3.** Section A of *R. raphana*, IGUT14512, ×120. **4.** Close-up of final chamber wall of figure 3, ×1, 500. ol: outer layer, il: inner layer. **5.** Close-up view of the biserial part in *R. raphana*, ×400, f: foramen, tp: toothplate, l: lip. **6.** Section A of *Rectobolivina striatula* (Cushman), IGUT14514, ×180. **7.** Oblique view of foramen and toothplate in *R. striatula*, IGUT14515. The toothplate extends into the chamber lumen. Its lateral edges strongly fold towards the opposite side of the preceding foramenal opening (f), but it never shows the tube-like structure, ×180.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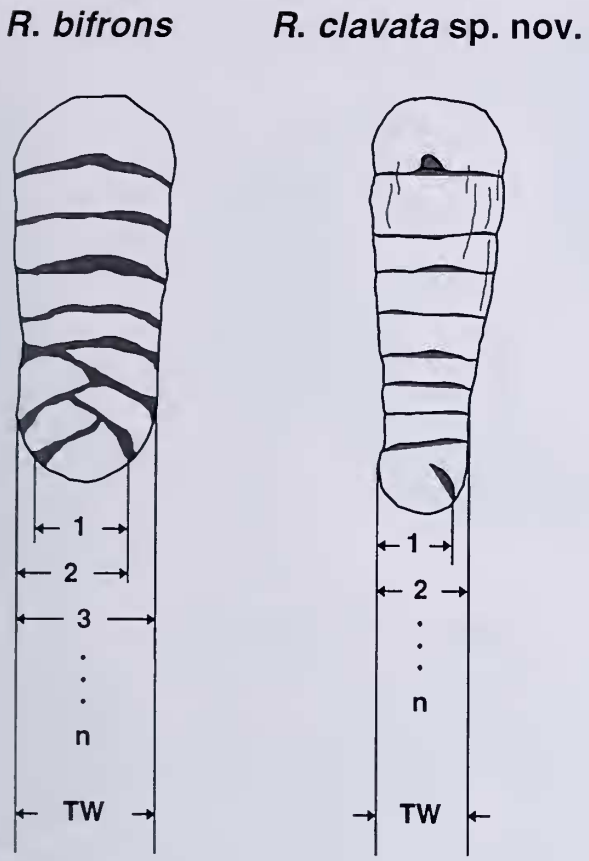

Figure 14. Definition of measurements. TW: Test width including the distal chambers. n: Number of chambers from the initial to final chamber.

Rectobolivina clavatostriatula nom. nov.

Figure 13.5

Siphogenerina bifrons (Brady) var. *striatula* Cushman, 1917, p. 662 (nomen nudum); Cushman, 1919, p. 620; Cushman, 1921, p. 278, pl. 56, fig. 4; Cushman, 1926, p. 18, pl. 2, fig. 6, pl. 4, figs. 1–3.

Rectobolivina bifrons (Brady) var. *striatula* (Cushman, 1917). Cushman, 1937, p. 205, pl. 23, figs. 17, 18.

Diagnosis.—A species of *Rectobolivina* with a clavate-shaped test covered by distinct longitudinal striations.

Etymology.—The new specific name, *clavatostriatula*, represents clavate test shape and distinct striations of this species.

Remarks.—Cushman (1917) reported this species from the Sogod Bay (~1,000 m water depth), Philippines, under the name of *Siphogenerina bifrons* (Brady) var. *striatula* Cushman. Later, Cushman (1921, pl.56, fig.4) illustrated it (here reproduced in Figure 13.5). However, *S. bifrons* var. *striatula* Cushman, 1917 is a junior primary homonym of *Siphogenerina striatula* Cushman, 1913 (the original figure of the holotype is reproduced in Figure 13.11a, b), reported from the western Pacific Ocean. The former can clearly be distinguished from the latter in having a clavate-shaped test with fewer but more raised striations on the test surface. Consequently, *Rectobolivina clavatostriatula* is proposed as a new name to replace *S. bifrons* var. *striatula* Cushman, 1917.

Rectobolivina discontinuosa sp. nov.

Figures 4.8a–c, 9a–c; 10.5–10.7; 13.6a, 13.7b

Rectobolivina bifrons (Brady) (non *Sagrina bifrons* Brady, 1881). Loeblich and Tappan, 1964, p. C553, fig. 438, nos. 2a–5b; Loeblich and Tappan, 1987, p. 517, pl. 567, figs. 11–14 (not figs. 15–17).

? *Rectobolivina bifrons* (Brady) var. *striatula* (Cushman). LeRoy, 1941b (non *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917, nomen nudum), p. 80, pl.1, fig. 9.

Diagnosis.—A species with a clavate-shaped test, whose surface is covered by numerous and discontinuous striations mainly on the later portion of the test.

Description.—Test free, moderate size, approximately four times as long as broad, straight, clavate-shaped, elliptical in being laterally depressed in cross section, initial end bluntly rounded in megalospheric form, pointed in microspheric form; chambers numerous, breadth twice the height, gradually increasing in size, changing from biserial to uniserial after the seventh chamber in megalospheric forms or after the thirteenth chamber in microspheric forms; wall calcareous, optically radial, transparent or semitransparent, finely perforate, rather thick, striae numerous in the later part of the test but much sparser in the earlier part of the test; sutures distinct, moderately thick, slightly depressed or flush; aperture terminal, nearly circular to elliptical, with a distinct lip; intercameral septa thick as well as the wall, parallel to slightly arched; toothplate folded at the side edge, extending into the preceding aperture (foramen), its folded face arranged alternately in position in planes 180° apart.

← **Figure 13.** Reproduction of original figures of the studied species. **1a, b.** *Rectobolivina asanoi* Murata, 1951, ×135. **2–4b.** *Rectobolivina bifrons* (Brady, 1881), after Brady (1884), ×71. **5.** *Siphogenerina bifrons* (Brady) var. *striatula* Cushman, 1917, after Cushman (1921) = *Rectobolivina clavatostriatula* nom. nov., ×66. **6a–7b.** *Rectobolivina bifrons* (Brady, 1881) of Loeblich and Tappan (1964) = *Rectobolivina discontinuosa* sp. nov., ×66. 6a, b: megalospheric, 7a, b: microspheric forms. **8a–10b.** *Rectobolivina raphana* (Parker and Jones, 1865) of Loeblich and Tappan (1964), ×55. 11a, b. *Siphogenerina striatula* Cushman, 1913, ×75.

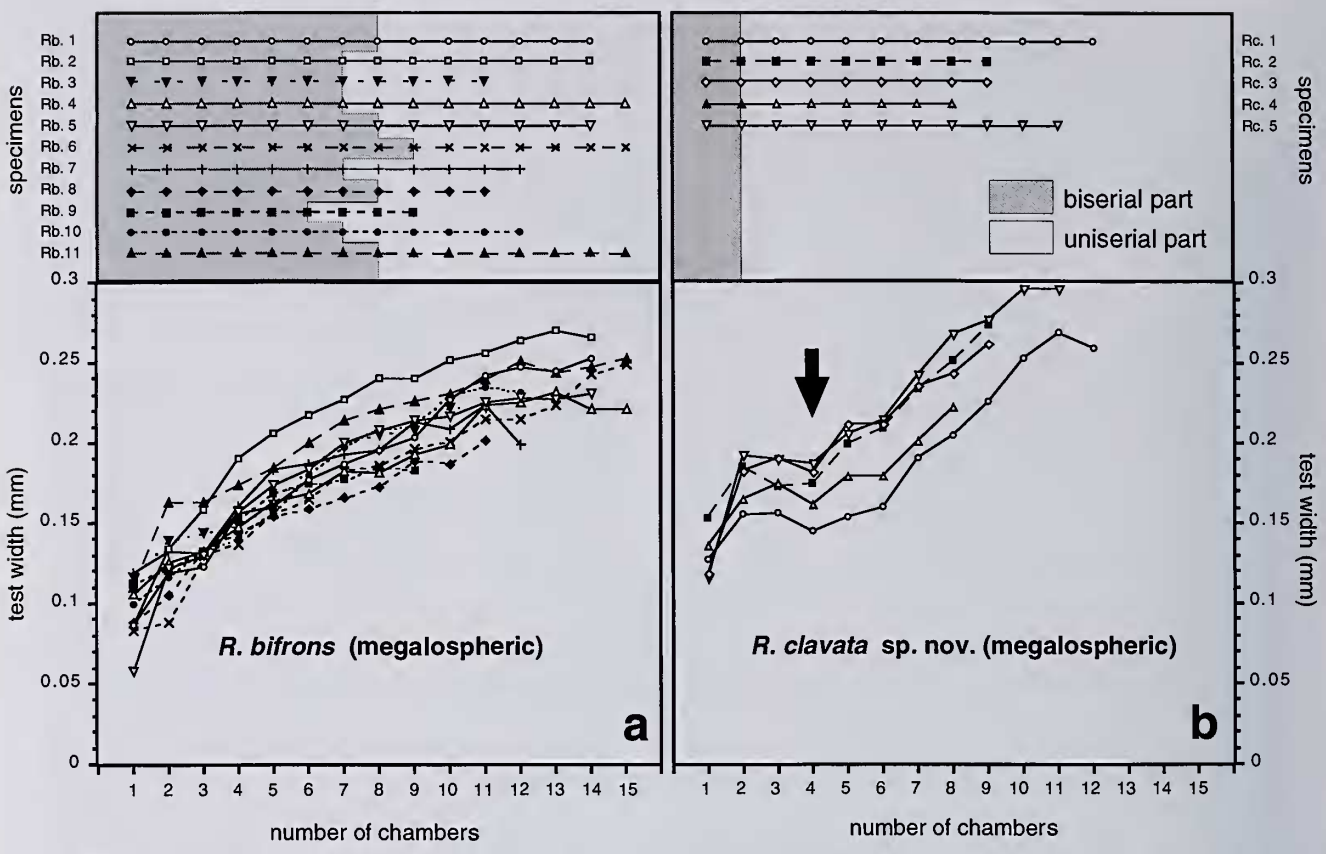

Figure 15. Test width changes in the megalospheric forms of *Rectobolivina clavata* sp. nov. (n = 5) and *R. bifrons* (n = 11) through ontogeny. Arrow indicates the position where the test width of *R. clavata* becomes the narrowest.

Material.—Holotype: IGUT14504 (0.98 mm in length, 0.31 mm in maximum breadth), sample MK57 (Figure 4.8a–c). Paratypes: IGUT14505 (1.05 mm in length, 0.31 mm in maximum breadth), sample MK57 (Figure 4.9a–c); IGUT14506, sample MK57 (Figure 10.5); IGUT14507, sample MK57 (Figure 10.6, 10.7).

Etymology.—The new specific name, *discontinuosa*, comes from the discontinuous striations of the test.

Remarks.—The specimens treated here (Figures 4.8a–c, 9a–c) are compared well with those of Loeblich and Tappan's (1964, 1987) *Rectobolivina bifrons* (here reproduced in Figures 13.6a–7b) in having a clavate-shaped test ornamented by distinct, discontinuous striations. This discontinuous striation is clearly distinguished from the completely continuous striation in typical *Rectobolivina clavatostriatula* (Figure 13.5) and from the inornate test of *Rectobolivina clavata* (Figure 4.5a–c, 4.6a–c, 4.7a–c). Therefore, we judge our specimens to belong to a new species and not to either of the latter two species. This new species differs from *Rectobolivina asanoi* Murata, 1951 by its more slender and clavate-shaped test with less raised striations on the test surface.

Rectobolivina raphana (Parker and Jones, 1865)

Figures 4.10a–c, 4.11a–c; 8.1; 11.1–11.5; 13.8a–13.10b

Uvigerina (*Sagrina*) *raphanus* Parker and Jones, 1865, p. 364, pl. 18, figs. 16, 17.

Sagrina raphanus (Parker and Jones). Brady, 1884, p. 585, pl. 75, figs. 21–24.

Siphogenerina (*Sagrina*) *raphanus* (Parker and Jones). Cushman, 1913, p. 108, pl. 46, figs. 1–5.

Siphogenerina raphanus (Parker and Jones). Cushman, 1921, p. 280, pl. 56, fig. 7; Cushman, 1926, p. 4, pl. 1, figs. 3, 4 (? figs. 1, 2), pl. 2, figs. 1–3, 10, pl. 5, figs. 1, 2; Cushman, 1942, p. 55, pl. 15, figs. 8, 9 (not figs. 6, 7); Hofker, 1951a, p. 233, figs. 155, 156; LeRoy, 1964, p. F35, pl. 3, fig. 35.

Siphogenerina raphana (Parker and Jones). Hada, 1931, p. 134, text-figs. 91a, b; Asano, 1950, p. 14, figs. 56, 57; Asano, 1958, p. 30, pl. 7, figs. 8–10; Kuwano, 1962, pl. 22, fig. 5; Ishiwada, 1964, pl. 5, fig. 81.

Rectobolivina raphana (Parker and Jones). Loeblich and Tappan, 1964, p. 533, fig. 438–9–11; Matoba, 1970, p. 60, pl. 3, fig. 31; Whittaker and Hodgkinson, 1979, p. 56, fig. 8; Matoba and Honma, 1986, pl.4, figs.6a, b; Matoba and Fukusawa,

1992, p. 218, fig. 9–6.

? *Siphogenerina* (*Sagrina*) *raphanus* (Parker and Jones). Egger, 1893, p. 317, pl. 9, fig. 36.

Material.—IGUT14508, sample MK56 (Figure 4.10a–c); IGUT14509, sample MK56 (Figure 4.11a–c); sample MK56 (Figure 8.1); IGUT14510, sample MK56 (Figure 11.1); IGUT14511, sample MK56 (Figure 11.2, 11.5); IGUT14512, sample MK56 (Figure 11.3, 11.4).

Remarks.—All specimens treated in this study are elliptically rounded in section, and in this respect, they are distinguished from the paratypes of this species designated by Loeblich and Tappan (1964) (here reproduced in Figure 13.8a–13.10b). Unfortunately, they did not show a figure of the lectotype. As was shown in many previous descriptions (see the above synonym list), strongly raised costae on the entire test surface are recognized in all specimens examined (e.g. Figure 4.10a–4.11c).

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